Operative Techniques in
Orthopaedics

Acute Deformity Correction and Lengthening with Motorized Nail: Surgical Technique

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Limb deformity with associated limb length inequality results from many causes and can lead to significant morbidity. Internal motorized nails have revolutionized the field of limb lengthening and allow for concomitant correction of deformity and limb length inequality without the use of external fixation. These devices can be used in many adult and pediatric cases, although care must be taken to assure that successful reconstruction without contraindications is possible. Planning for an optimal outcome with these devices requires careful preoperative planning and attention to a number of technical points not typical of other treatment strategies. We also present a novel osteotomy method, the "comminuted closing wedge osteotomy," that we have found to be beneficial in allowing for correction of larger magnitudes of deformity than would otherwise be possible and with notably improved regenerate bone formation when performing large angular corrections. Internal motorized nails combined with appropriate planning, an optimal osteotomy, appropriately placed stabilization screws, and soft tissue management offer an exciting and powerful advance in our ability to treat combined long bone deformity and shortening.
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Introduction

Limb deformity with associated limb length inequality can result from congenital, developmental, or post-traumatic conditions. The combination of malalignment and limb length inequality can be very problematic for the patient. Many patients early in life or recently after injury complain of the deformed and shortened appearance of their extremity as well as the alterations in gait and associated limp. However, the problem becomes much worse with time as the mechanical effects of the altered gait take a toll on the joints. Adjacent joints nearest to the bony deformity are most frequently affected first, but over time other joints in both the ipsilateral and contralateral extremity as well as the lower spine can develop degenerative changes.

Since the earliest days of orthopaedic surgery, efforts have been made to prevent and treat limb deformity and length inequality.[1] Over the years, many methods have been proposed for correction of malalignment.[2] These include various forms of fixation such as plates and screws, external fixation, and static intramedullary nails. There have also been multiple proposed ways to cut the bone for correction including opening wedge, closing wedge, neutral wedge, mathematically directed single-cut, and clamshell osteotomy techniques.[3-8] Combinations of these fixation and osteotomy techniques have proven capable of correcting many deformities.

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However, until recently the only 1 of these methods that was capable of correcting deformity and also reliably lengthening an extremity more than a modest amount was external fixation.

The Ilizarov method and distraction osteogenesis using external fixation provided the first effective method to perform even large amounts of lengthening of an extremity.[9,10] Ilizarov's method allows for both correction of bony deformity and lengthening simultaneously and remains an effective technique, but it is technically demanding and cumbersome. Technical ease of correcting alignment greatly improved with the introduction of the Taylor Spatial Frame hexapod external fixator in 1996. However, both Ilizarov and hexapod fixators are external fixation devices that are cumbersome and problematic for patients and many corrections require 6-12 months or more in the external fixator for healing until it can be removed.[11]

The introduction of internal motorized lengthening nails (IMLNs) has now provided a reliable option for performing distraction osteogenesis without the need for external fixation. IMLNs have proven to be very effective at bone and limb lengthening with fewer complications and greater patient ease than external fixation. Methods have been described that effectively allow for planning to correct deformity and allow lengthening using these devices.[12-16] However, there have been challenges with correcting larger magnitudes of deformity using these devices. The purpose of our discussion below is to describe the methods of performing acute deformity correction and subsequent gradual lengthening with distraction osteogenesis using IMLNs. In addition, we introduce a new osteotomy concept, the comminuted closing wedge osteotomy, that facilitates correction of greater amounts of angular deformity while encouraging superior regenerate bone formation than the traditional opening wedge osteotomy when correcting large angular deformities.

Indications

Various thresholds of deformity have been proposed as surgical indications with $>5^\circ$ of varus, $>10^\circ$ valgus, $>10^\circ$ sagittal plane (apex anterior/posterior), or $>10^\circ$ rotation most often referenced. However, these numbers are somewhat arbitrary as deformities rarely occur in 1 plane and there is no well-validated method for summing the various parts to reach clinically meaningful conclusions. Another issue is that individual patients have different tolerance for what they consider cosmetically acceptable and symptomatically tolerable. Indications for correction of limb length inequality are similarly controversial. Traditionally >2 cm was considered appropriate; however, the improved safety and efficacy or limb lengthening with IMLNs has changed the risk benefit ratio substantially. Consequently, correction of symptomatic limb length differences as small as 8-10 mm may be a more reasonable threshold. For these reasons, the above criteria are most useful as a starting point for a patient conversation to determine a plan based on all aspects of the problem and their goals.

Once a determination to proceed with reconstruction is made, IMLNs are the most optimal device for deformity correction and lengthening when feasible. IMLNs can be placed retrograde in the femur in both adults and children. This is because central perforation of the growth plate with less than 7% of surface area replaced with an intramedullary device has no negative effect on growth potential and does not create deformity.[17] IMLNs can also be placed antegrade in the femur and tibia in adults and likely also in older adolescents as Court-Brown demonstrated that tibial nailing in this age group did not cause sequelae.[18] However, antegrade placement in the femur and tibia is not well studied in younger children with open growth plates and must be undertaken with caution as this may lead to asymmetric growth and deformity and possibly growth inhibition.[3]

One must also consider if it is feasible to pass an intramedullary nail through the intramedullary canal. Very small canal diameter and bone size may prevent nail passage. The same can be true for severely continuously curved bones that would require an excessive number of osteotomies to allow nail passage. In addition, any risk of infection must be eradicated prior to considering placement of an IMLN and if this is not possible, then they should not be used.

Finally, it is critical to evaluate the center of rotation and angulation (CORA) of the deformity and determine the location of the osteotomy needed for correction. If the CORA is very close to the joint, it may not be feasible to perform an osteotomy that will both allow for correction and provide adequate bone stock for stable fixation of the intramedullary nail. If this is the case, then an alternative strategy should be considered such as correction of the deformity with an osteotomy fixed with plates and screws and either a simultaneous separate lengthening on the other side of the bone or a separate procedure for lengthening after the corrective osteotomy has healed. Alternatively, external fixation device may be a more powerful option to accomplish the surgical goals in a single setting.

Surgical Technique

Preoperative Planning

There are 2 ways to approach planning for deformity correction and concomitant bone lengthening with an IMLNs. The "reverse planning method" proposed by Baumgart and the more standard deformity analysis approach based on the anatomical and mechanical axis as described by Paley and the method described by Fabricant.[3,19-24] The reverse planning method is tailored to the use of an IMLNs and is very precise in its approach. The more standard methods involve some approximations and fudge factor when used in the femur but can also be effective in achieving optimal results. Regardless of the planning approach, there are key differences from planning for external fixation. The first is that the planned osteotomy(s) must allow for the nail to pass within the intramedullary canal with room on both ends of the bone for adequate fixation in the nail. The second is that unlike external fixation where lengthening can be performed along the mechanical axis, motorized nails require lengthening along the axis of the nail. In most bones the anatomical and mechanical axes of the bone are similar, but in the femur the 2 axes are divergent so lengthening along the anatomical axis will cause a lateral translation of the weightbearing axis in the coronal plane. Accommodation for axis deviation during lengthening must be made at the time of osteotomy and nail placement as later adjustments are not possible with an all internal method.[3]

Planning must begin with adequate imaging, which includes full length images in both the AP and lateral planes of the entire lower extremity. If a rotational deformity is suspected, then CT scans should be used to quantify the magnitude. In addition, 2 views of the lower extremity must be obtained with 1 having the patella pointing forward and the other with either the ankle or hip appropriately positioned, depending on which limb segment is being evaluated. The reverse planning method assumes that reaming will be done in a preplanned way to accommodate a straight nail and not the path of least resistance. Straight rigid reamers can be very helpful for this and are recommended by Baumgart.[3] Flexible reamers can be used but require blocking pins or screws to adequately control the reaming process.

The principle of the reverse planning method is to start the planning with the "ideal" final result and to proceed step by step in reverse to the original status.

Starting Point

The starting point for most IMLNs is the same as what would be used for a standard intramedullary nail. One common exception to this is that in the distal femur it may be necessary to move the starting points a few millimeters anterior to accommodate the straight nail.

Osteotomy

Many reports validate that osteotomies performed with the multiple drill hole technique leads to excellent healing times when used with IMLNs. There is also strong evidence from external fixation literature that osteotomies performed with a Gigli saw can be equally efficacious, although there are far fewer reports of this with IMLNs.[25-27] The core principals of performing an osteotomy for lengthening with an IMLN are the same as for those established for external fixation including minimizing soft tissue stripping, a low energy osteotomy, and minimal heat generation at the osteotomy site.

Reports of concomitant bone lengthening with deformity correction using IMLNs have universally employed an opening wedge osteotomy using the multiple drill hole technique for acute correction of modest deformities with good results. Fragomen reported on 27 cases in the femur with an average of 7 degrees deformity and a maximum of 15-20 degrees with acceptable results for bone healing.[19] However, there is concern for the quality of bone formation with larger amounts of acute correction, especially in the tibia.[20]

The author has found that the use of a novel osteotomy technique, the "comminuted closing wedge osteotomy" is very helpful in facilitating acute deformity correction of larger magnitudes with bone lengthening in both the femur and the tibia. In addition, this osteotomy technique can sometimes allow for correction of the deformity at a level in the bone that permits for adequate nail fixation that otherwise may not have been possible.

The technique is illustrated in Figure 2 and Figure 7. It essentially involves making a percutaneous series of drill holes that will allow creation of a comminuted wedge of bone at or near the apex of the deformity. The area is then comminuted before the osteotomy is completed much like directing a tree to fall when it is cut down. The osteotomy is allowed to close down on itself creating excellent bony apposition at the osteotomy site with a large amount of small vascularized comminuted bone fragments surrounding it. This creates an optimal environment for initial regenerate formation even with massive angular corrections. Simple opening wedge osteotomies are faster and simpler to perform and likely fairly equivalent for smaller angular corrections, but as magnitude of corrections gets larger and certainly above 10 degrees it is a worthwhile alternative.

Blocking (Stabilization) Wires and Screws

Blocking screws were introduced for use with intramedullary fracture fixation in 1999 and have proven very useful in the treatment of metaphyseal fractures. Blocking screws help better align the bone by "blocking" the nail's ability to enter a part of the widened canal that would lead to deformity. The screws in effect create a neocortex for containment of the nail. When using IMLNs, blocking or stabilization screws take on an even greater importance. These screws can be placed to redirect the nail before it is placed or if malalignment occurs during nail placement as blocking screws. However, with IMLNs the screws are often placed after the nail is already in an optimal position in order to provide greater stability and prevent drift into deformity during the lengthening process. The key here is that the stabilization screws are placed adjacent to the IMLN on sides of the nail that do not abut a cortex in order to constrain the nail and limit its ability to wobble around or drift into deformity within the bone during distraction or compression.

The author finds that using blocking wires, which are typically 2.4 mm Steinmann pins, used to control reaming and direct nail placement provides significant advantages (Figs. 2 and 7). The wires can be easily repositioned if needed without leaving a significant hole in the bone. In addition, given their smaller footprint and greater flexibility, it is less likely for a fracture to extend into them during reaming or nail placement than with a larger screw. After the nail has been ideally placed, the wires can be replaced with screws that are placed as stabilization screws directly adjacent to the nail when the nail is in its final ideal position. If the screws are placed as blocking screws prior to reaming and nail placement, it is much less likely for them to be placed in the absolutely optimal location.

Ex-fix Assisted

External fixator assistance can be helpful to assure proper reaming and maintenance of optimal rotation. The author typically uses a tension wire assisted distractor to assist with correction of tibial deformity similar to the protocol reported for acute fractures.[28] The author typically does not use

Figure 1 (A, B) AP and lateral radiographs of a 62-year-old woman with a history of a motor vehicle crash at age 13. The patient has left leg shortening combined with deformity of 12° valgus, 15° apex posterior, and mild internal rotation of the distal femur. (C) AP radiograph after right total hip arthroplasty prior to referral. The THA improved right hip function but increased the limb length difference and left knee arthritis symptoms. The patient has right knee flexion in this XR, but length difference was determined from original AP + additional height from arthroplasty.

external fixation during femoral corrections and relies primarily on blocking wires, however, external fixation can be useful in the femur as well and can be quite simple with a single pin on each side of the fracture or a monolateral rail external fixator. Regardless of whether an external fixator is used, it is helpful to have a Schanz pin in both the proximal and distal segment as a rotational reference during the correction.

Latency and Rate of Distraction

The basic latency and distraction rate established by Ilizarov for use with his method was a 7-10-day latency period and distraction at a rate of 1 mm/d split into 4 of 0.25 mm sessions.[9,10,29,30] Generally speaking, these rates can work well with IMLNs as well, especially for the femur and humerus. However, the author typically recommends a longer latency period of 10-days and a rate of 0.6 mm/d split into 3-4 sessions/day for the tibia.

Soft Tissue Management

Soft tissue management involves issues related to prevention and or treatment of contracture, nerve compression, and compartment syndrome. Most patients with post-traumatic deformity from a fracture in late adolescence or adulthood do not require soft tissue release prophylactically for prevention of contracture. The same is true in the tibia for patients with congenital and developmental causes, but in the femur, they almost universally benefit from release of the iliotibial band both distally near the knee and proximally near the greater trochanter. Some authors have also advocated for a limited quadriceps release and this is an option for patients who will be undergoing a long lengthening.[5,8,19-21,31] However, doing this early in the lengthening may increase the possibility of developing a problematic flexion contracture, which can be reason to have to stop the lengthening. Extension contractures can be more easily treated both during and after lengthening and so the author prefers to defer these more aggressive measures until either a problem arises during lengthening or in the post-lengthening period.

Another consideration with acute correction of deformity in the tibia is compromising the peroneal nerve, especially with correction of rotation and valgus. This complication is preventable if a peroneal nerve release is performed. The nerve should be released all along its course around the proximal fibula as well as proximally toward the knee and distally to the anterior compartment. In addition, large acute tibial

Figure 2 (A, B) Intraoperative XR showing starting guidewire and use of a normal starting point in the distal femur. The guidewire is aimed at the site the osteotomy will be performed. (C) The site of the osteotomy is identified, and a percutaneous incision is made for placement of a drill. (D) An initial pass of drill holes is made at the site of the future osteotomy. The drill line is made at an oblique to allow for a wedge of comminution. (E) A second drill line is made in order to complete the outline of the wedge and then additional drill holes are made within the wedge. (F) The osteotomy is made be first comminuting the wedge and then completing the osteotomy at the apex using the osteotomy and a wrench for the handle. A zone of comminution is produced on both the posterior and medial aspects in this case to allow for correction of valgus and apex posterior. (G) Alignment after the osteotomy. (H) A blocking wire is placed to control reaming. (I) The lateral distal femoral angle is measured after nail placement and confirmed to match the preoperative plan. (J) Locking screws and a stabilization screw is placed to prevent drift back into valgus during lengthening. (K) The fluoroscopy machine is adjusted to increase the KVs to allow for visualization of the magnet within the nail. The location of the nail is marked out and the function of the nail is tested with an ERC controller. In this case, the nail was pre-distracted by 1 cm, so the nail was tested in compression.

Figure 3 (A-D) Postop radiographs showing aligned femur with compressed osteotomy site.

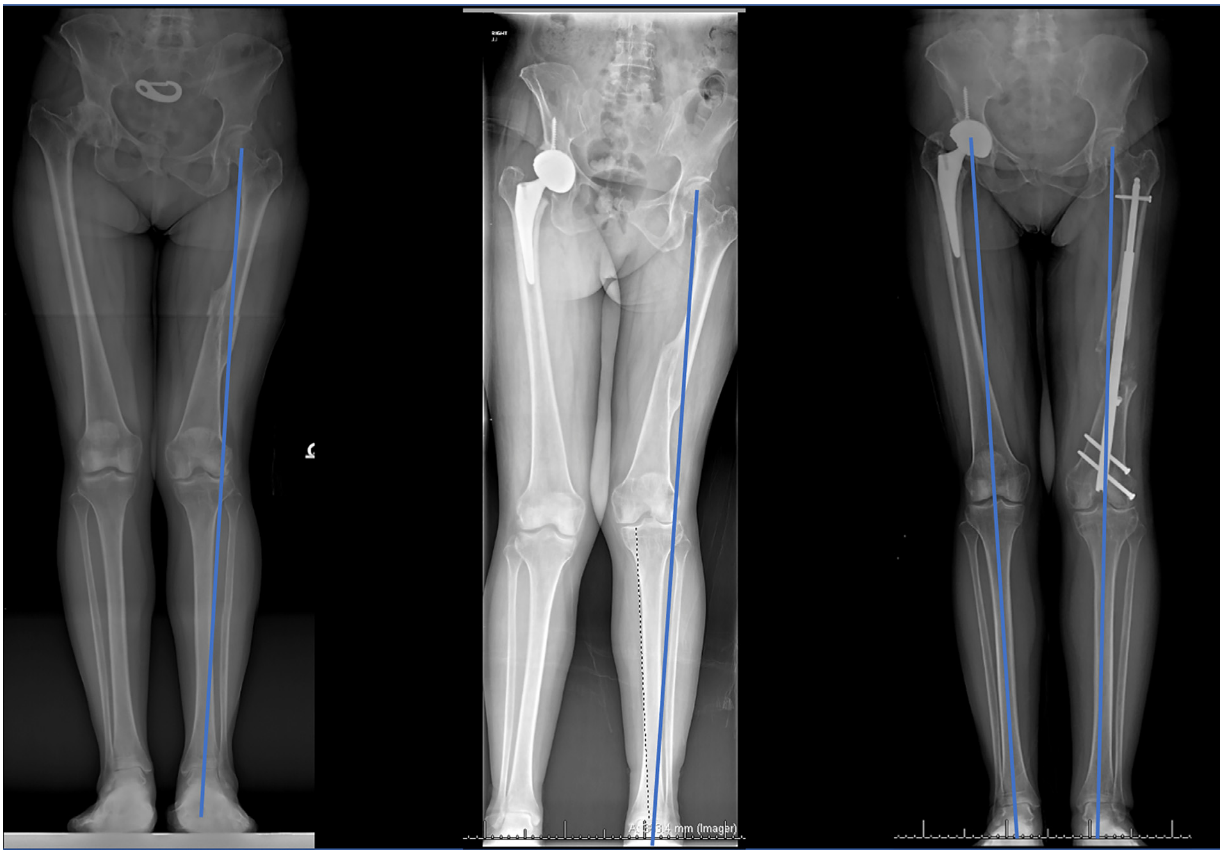

Figure 4 (A-C) AP radiographs at first presentation, post-THA, and 4 days prior to completion of lengthening with alignment corrected.

Figure 5 (A, B) AP and lateral 8-month follow-up XRs of healed well-aligned and lengthened femur.

corrections have a risk of compartment syndrome, especially involving the anterior and lateral compartments. For this reason, a fasciotomy of the anterior and lateral compartments is recommended. This can easily be performed with a percutaneous fasciotomy thorough the same incision that is made if a peroneal nerve release is performed. Typically, a posterior compartment release is not performed but can be if there is concern.

Clinical Case Example 1

The patient is a 62-year-old woman with a history of a left femur fracture from a motor vehicle crash when she was 13 years old. She was treated nonoperatively and healed with valgus, apex posterior, internal rotation, and shortening of the left femur as seen in Figure 1. She had her right hip replaced 6 months prior to referral, which gave her a good leg for mobilization, but exacerbated the leg length difference and symptoms in the left knee.

Planning for reconstruction was done using the reverse planning method and the site of the osteotomy was determined to be just distal to the circumferentially intact cortex of the original proximal fragment. At this level, the anatomical lateral distal femoral angle (aLDFA) should be 82 degrees to reach an anatomical alignment at the end of lengthening. The parameters for correction included lengthening of approximately 50 mm, correction of 12 degrees valgus, 22 mm medial translation, 26 mm posterior translation, 5 degrees internal rotation, and 15 degrees apex posterior deformity. Length measurements were an approximation between the XRs taken prior to THA with the amount of length from the THA added given that in her standing view her right knee is in some degree of flexion. The plan for correction assumes a normal distal femoral starting point as seen in Figures 2A and B.

Figure 2C shows marking of the osteotomy location and Figures 2D-G show the sequence for performing a "comminuted closing wedge osteotomy". This osteotomy is performed completely percutaneously through either 1 or 2 holes depending on the exact configuration required. The osteotomy begins with a line of drill passes at an oblique to the axis of the proximal segment. A second line of holes is then made distal to the first and is made to form a wedge on the closing side of the osteotomy. The size of the wedge depends on the size of the angular correction to be performed. After the wedge is formed, the drill is passed several more times in the center of the wedge and a small osteotome is used to comminute the wedge portion of the osteotomy. If the deformity requires correction in more than 1 plane, then a wedge of comminution should be performed centered on the expected apex of the combined deformity. After the wedge has been broken into smaller fragments, the osteotomy is completed on the far side and the deformity corrected. This allows the bone edges to be well apposed as opposed to an opening wedge osteotomy for large acute angular correction that causes a large gap at a portion of the osteotomy site. In addition, the comminution provides the equivalent of local vascularized bone graft to assist in forming high quality regenerate at the start of lengthening.

After the osteotomy, blocking wires are used to control the reaming process as seen in Figure 2H. The nail is passed and the anatomical lateral distal femoral angle is checked relative to the position of the nail as in Figure 2I to assure an accurate correction. The nail is locked distally and proximally, and a stabilization screw is placed adjacent to the nail only on the lateral side only since the medial side is captured by the femoral cortex. Stabilization screws (aka blocking screws) are essential when using motorized nails to prevent the development of deformity during lengthening.

In this case, the nail has a stroke length of 8 cm meaning that the nail can lengthen a maximum of 8 cm. Because we did not need 8 cm of lengthening, we were able to pre-distract the nail 15mm prior to placing the nail. Pre-distraction has 2 advantages with the first being that the nail can be tested in compression of the osteotomy site instead of distraction after it is placed. This provides the opportunity to allow good bone apposition during the latency period when initial callus is forming. The second benefit is that if for any reason there is no good regenerate formation or infection that destroys it, it will be possible to completely reverse the nail to compress the osteotomy site to encourage a restart of the regenerate or to get the osteotomy to heal as needed. Figure 2K shows the magnet being marked out prior to using the ERC controller to test the nail in compression. Figures 3A-C are postoperative x-rays that show excellent alignment and compression of the osteotomy site with surrounding small, comminuted bone fragments.

The lengthening begins after a 7-day latency period and progresses at 1 mm per day split into 4 sessions of 0.25 mm 4x daily. The lengthening proceeds according to the preoperative plan until the lengths are close to equal and then radiographs should be checked against clinical examination to assure appropriate leg length for the patient is achieved. Figure 4 shows the change in alignment and leg length from the original condition to radiographs taken 4 days prior to completion of lengthening. The alignment has been optimized and regenerate formation is appropriate. Figure 5 reveals the very solid healing that is present at 8 months. The patient is progressing well, and we plan for routine removal of the nail at 1 year as is our protocol with all IMLNs.

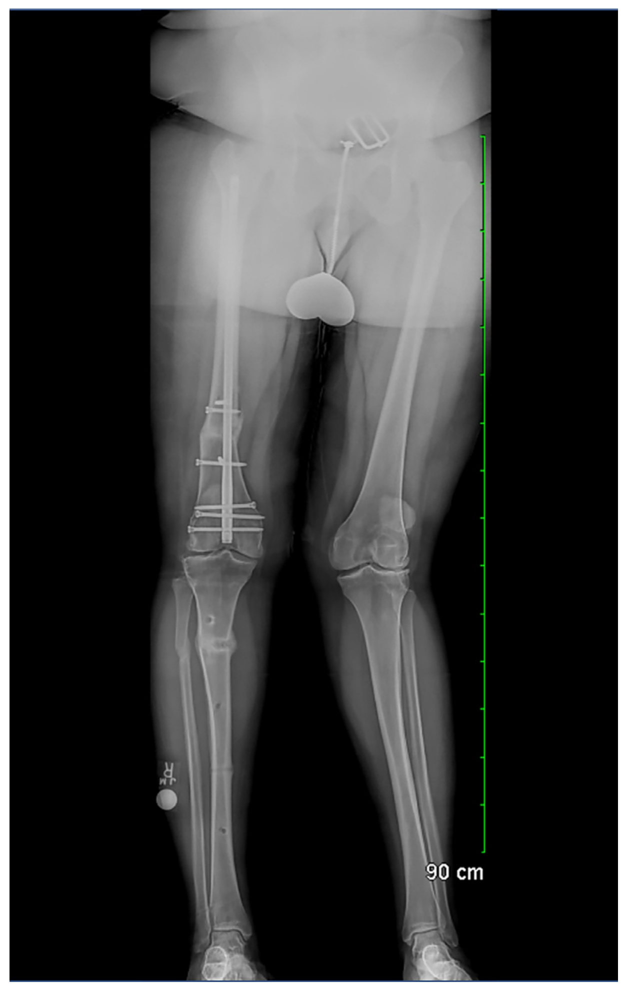

Figure 6 AP radiograph of patient with a congenital malalignment. The left side has external rotation and valgus deformity of the distal femur and an internal rotation with valgus deformity with limb length inequality of the tibia. The contralateral side had similar deformities and the femur was corrected with a static intramedullary nail while the tibia was corrected with a hexapod external fixator into mild overcorrection in varus for lateral sided arthritis that was worse than that on the left.

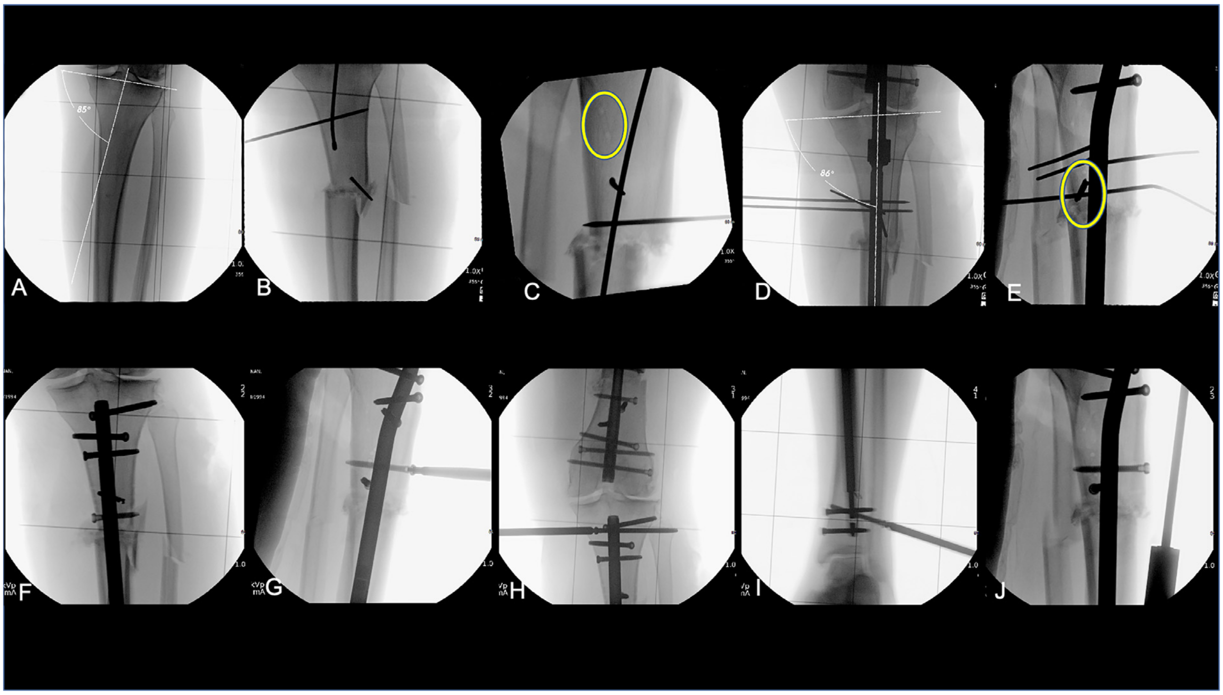

Figure 7 Intraoperative fluoroscopic images of the tibial correction. (A) The site of the osteotomy is determined using medial proximal tibial angles identified in the preoperative plan. (B) A comminuted wedge osteotomy is performed with a medial wedge. The osteotomy was allowed to butterfly on the far side in order to allow for the substantial rotational correction that was required. (C) Blocking wires are used to control the path of reaming. Blocking wires are preferred over screws because they can be easily adjusted without leaving significant holes as shown in the circle. (D) The nail is placed and appropriate alignment in rotation and angulation in AP and lateral planes is confirmed. (E) After placement of locking screws, a stabilization screw is placed behind the nail as seen with the drill bit outlined. The posterior blocking wires are removed after the screws are placed. (F-G) A stabilization screw is also placed lateral as the cortex contains the nail medially. (H-I) Syndesmotic fixation is mandatory for the lengthening to protect the proximal and distal tibiofibular joints. These screws are typically placed with a guidewire and cannulated drill followed by screw placement. The distal screw is angulated to provide greater control for prevention of fibular migration. (J) After all locking and stabilization screws are placed, a Fast Distractor Max is used to test the function of the nail and compress the osteotomy site.

Clinical Example 2

The patient is a 26-year-old man with a history of congenital deformity including bilateral severe rotational and valgus deformities of both femurs and tibias. The patient had a correction of his right side 12 months prior to the current surgery in which he had a rotational osteotomy and blocking screw assisted nailing of his right femur as well as an osteotomy and correction of deformity in his right tibia with a hexapod external fixator. After achieving anatomical joint line angles in the femur and tibia, the tibia was overcorrected into mild varus to offload the comparatively more severe lateral sided arthritis with the hexapod fixator. The patient wished to avoid the use of external fixation on the left side for correction of his contralateral deformity if possible (Fig. 6).

The plan for correction of the femur on the left side was for placement of a retrograde femoral nail and blocking screws similar to the right side. The proximal femur is normal, and planning was made for correction of both rotation and valgus through a distal metaphyseal comminuted closing wedge osteotomy. It should be noted that isolated rotational osteotomies in the femur are typically performed in the proximal femur so that the quadriceps muscles are reoriented with the distal femur, but in this case, we decided on a distal osteotomy to allow concomitant correction of valgus deformity in this location. The plan for the tibia is for acute correction of deformity through proximal tibial metaphyseal and fibular osteotomies and placement of a weightbearing IMLN with stabilization screws. The leg length difference will be corrected postoperatively using the IMLN. Deformity planning was performed using standard planning methods of CORA and joint angles given that the only lengthening to be performed is in the tibia.

It is important to note that prior to performing the osteotomy, we addressed soft tissue concerns. It is often quoted that the peroneal nerve is at risk with corrections of external rotation deformity in the tibia due to the fascial constraints as the nerve crosses the neck of the fibula. This is true, but it is under recognized that large acute corrections of internal rotational deformity can also damage the nerve in a similar fashion due to constriction at the anterior compartment

Figure 8 Post-op radiographs of the tibia and femur now well aligned. Note the vascularized comminution at the osteotomy site.

fascia. In addition, there is a potential risk of compartment syndrome, especially in the anterior compartment, with this magnitude of acute correction. For these reasons, we began with a complete release of the peroneal nerve as it crossed the fibular neck and entered the anterior compartment. We then performed a percutaneous release of both the anterior and lateral compartments using a percutaneous fasciotomy from the incision used for release of the peroneal nerve.

With the soft tissue concerns addressed, we began with correction of bony deformity as seen in Figure 7. We identified the osteotomy site using joint angles (Fig. 7A) and performed a comminuted closing wedge osteotomy with a medial wedge (Fig. 7B). In most circumstances we try to avoid comminuting the far side of the osteotomy, but in the case of major rotation deformity such as this it is sometimes useful if a far-sided butterfly is serendipitously created.

Blocking wires are used to control the path of reaming. Blocking wires are preferred over screws because they can be easily adjusted without leaving significant holes behind when they are repositioned as seen in (Fig. 7C). The nail was pre-distracted 2 cm prior to insertion and then passed. The alignment was confirmed with the nail in place by checking the medial and posterior proximal tibial angles (Fig. 7D). If the correction achieved is less than planned, the nail can be temporarily removed and additional comminution of the osteotomy site in the zone of the wedge can be performed after which the nail is replaced. Stabilization screws are placed in locations adjacent to the blocking wires next to the nail and the wires are removed (Figs. 7E-G). It should be noted that although blocking wires are a powerful tool and more versatile then going directly to screws, there are a few caveats. The first is that the wire should be controlled with a Kocher clamp during reaming to prevent it from being advanced forward as the reamer passes. In addition, the wires should be removed with a heavy needle driver and a back-and-forth twisting motion or a T-handle chuck and mallet instead of with power to prevent the pin from shearing off at the bone surface.

Once the tibial fixation is complete, the next step is to stabilize the proximal and distal tibiofibular syndesmoses. The proximal fixation is usually placed with a percutaneous wire from the fibular head on the lateral side exiting out medially passed in a posterolateral to anteromedial direction (Fig. 7H). The screw path is then over drilled from the medial side and a screw is placed from medial to lateral from the tibia into the fibular head. Placing the fixation from this direction tends to minimize the hardware prominence over the fibular head, which is a location in which prominent hardware becomes very symptomatic. The distal fixation is also placed using a guidewire and a cannulated drill. The distal end should be place at an angulation from more distally on the lateral side to more proximally on the medial side (Fig. 7I). This trajectory provides greater stability to the ankle joint during distraction than either a straight screw or 1 angled in the opposite direction. Following placement of all fixation, the nail is tested, and, in this case, a Fast Distractor Max was used to compress the osteotomy site and confirm function of the nail.

The postoperative result shows the reduction of each bone segment is ideal with an anatomical femur and just a couple degrees of varus built into the tibia to accommodate for joint line incongruity. (Fig. 8) The most recent radiographs show equalization of leg lengths and acceptable alignment in both lower extremities (Fig. 9).

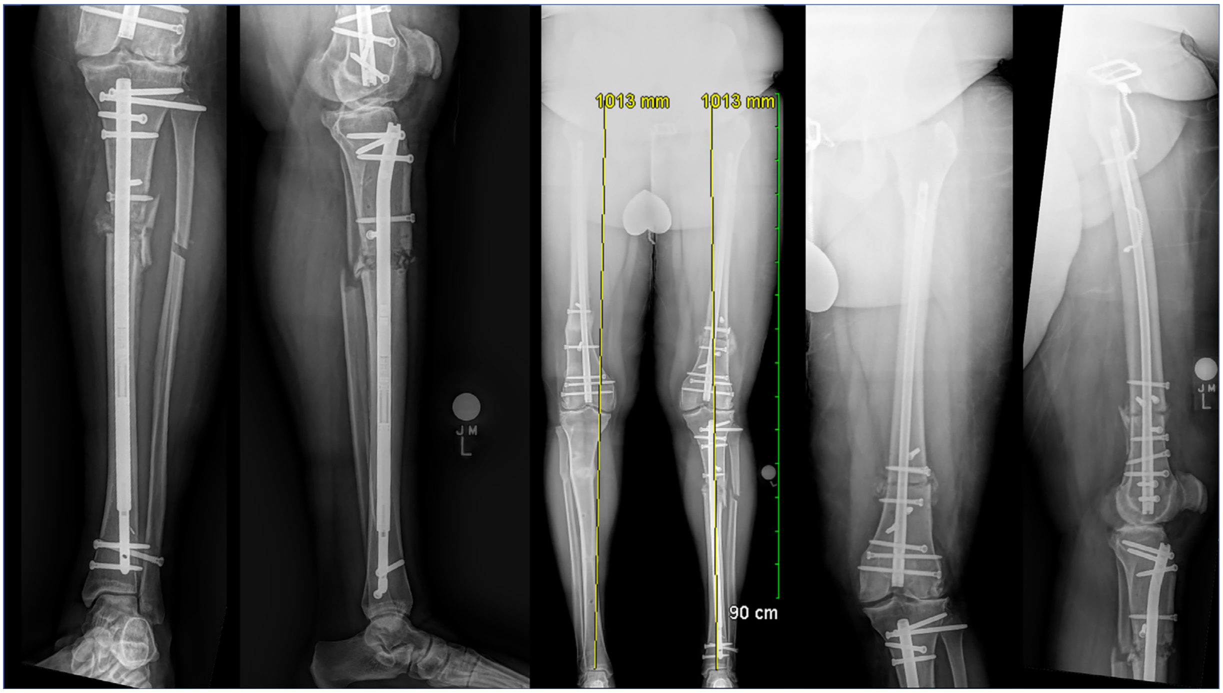

Figure 9 Radiographs of the bilateral lower extremities showing equalized leg lengths and greatly improved alignment that is now acceptable. There is excellent regenerate formation at the site of the osteotomy and lengthening.

It is interesting to note that the right side has a weightbearing axis that is essentially normal due to the overcorrection of the tibial alignment with the external fixator, but there is some varus of the anatomical axis of the tibia that is accommodating for mild joint line incongruity. Whereas on the left side the bones have been reconstructed to nearly normal anatomy with only very modest varus in the proximal tibia, but the weightbearing axis despite being close to anatomical is still slightly lateral due to joint line incongruity. These kinds of trade-offs are common in patient with long-standing severe bony deformity and arthritis, and it is unclear which is ultimately better for the patient. This patient currently feels well on both sides and is extremely happy with both corrections. However, when pressed he feels the left is perhaps a little better than the right. It will be interesting to see how he feels with long-term follow-up. Apart from this consideration, both of these cases clearly demonstrate in multiple limb segments the effectiveness of deformity correction and lengthening with IMLNs and also show the utility of the comminuted closing wedge osteotomy.

Conclusion

IMLNs have proven to be a powerful tool for safe and effective lengthening of an extremity. These devices also present a superior option for treatment of concomitant deformity and limb length inequality without the use of external fixation. The use of blocking wires and stabilization screws as well as external fixator assistance can aid in achieving optimal results. Soft tissue concerns such as nerve, compartment, and fascial releases are also critically important to safely performing many larger acute corrections. Correction of smaller degrees of deformity with limb lengthening is relatively straightforward with appropriate preoperative planning and a standard opening wedge osteotomy. However, a comminuted closing wedge osteotomy combined and initial osteotomy compression by the nail may provide a more reliable and reproducible method for correcting large angular deformities associated with shortening. Ultimately, the complete control of bone length provided by IMLNs allows us to view the correction of combined problems through a new lens and allows for a new paradigm regarding the treatment of combined deformity and limb length inequality.

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